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Design and Development of a Smart Motion Detection System Geared Towards Energy Conservation at a State University in Bacolor, Pampanga

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ABSTRACT

Energy waste remains a significant issue in educational institutions, where lights and ventilation systems are often left operating in unoccupied rooms. This study focuses on the design and development of a Smart Motion Detection System implemented in Classroom B103 of the CEA Building at Don Honorio Ventura State University, Bacolor, Pampanga. The system integrates motion sensors, microcontrollers, relay modules, and magnetic contactors to automatically turn off lights and fans when no movement is detected. It supports compliance with national energy policies, including Republic Act No. 11285, Administrative Order No. 15, and the university's Energy Efficiency and Conservation Unit Policy. A design and development research methodology was employed, supported by quantitative analysis of energy consumption. Comparative data over a 10-day period showed a reduction in electricity usage from 33.91 kWh to 18.5 kWh, marking a 45.44% decrease. System improvements, such as passive infrared sensor recalibration and an SMS notification feature, enhanced reliability and usability. Findings demonstrate that the Smart Motion Detection System is both effective and scalable, offering a practical solution for reducing energy waste in academic settings. The study recommends its wider adoption in other classrooms and public buildings to foster sustainability, reduce operational costs, and support energy conservation goals.

Keywords: Automation; Classroom Management; Detection; Educational Institutions; Electricity Usage; Energy Conservation; Energy wastage; Occupancy Sensing; Policy compliance; Sustainability.

1. Introduction

Energy waste is a critical environmental issue worldwide, significantly contributing to greenhouse gas emissions and the depletion of natural resources. This underscores the urgent need for effective energy management strategies [1]. In the Philippines, the government has addressed this challenge through key policies such as Republic Act No. 11285, institutionalizing energy efficiency and conservation [2], and the President's Administrative Order No. 15, which reinforces these efforts [3]. These national initiatives demonstrate a firm commitment to reducing energy consumption and advancing sustainability. At the institutional level, Don Honorio Ventura State University supports these national goals through its Energy Efficiency and Conservation Unit Policy. This policy mandates energy-saving practices across all campuses and facilities and encourages employees and students to actively participate in energy conservation initiatives. It emphasizes practical measures such as turning off lights and fans when not in use and supports research-based projects aimed at reducing energy waste [4].

Simultaneously, the increasing adoption of smart technologies plays a vital role in mitigating energy waste by enabling precise monitoring and control of energy use. Smart systems automate these processes, enhancing energy conservation without sacrificing user comfort [5],[6]. Among these, motion sensors are widely employed in intelligent building systems to detect occupancy and minimize unnecessary energy consumption [7],[8]. These sensors provide the foundation for automated systems that improve energy savings in practical and scalable ways [9],[10].

This study focuses on the design and development of a Smart Motion Detection System for Classroom B103 in Don Honorio Ventura State University's CEA Building B. The system integrates Passive Infrared Sensors, an Arduino

microcontroller, relay modules, and magnetic contactors to automate the control of lighting and fan systems based on occupancy detection, aiming to promote energy conservation.

1.1. Study Objectives

The objectives of this study are to:

1) Design a Smart Motion Detection System integrating Passive Infrared Sensors, an Arduino microcontroller, relay modules, and magnetic contactors for automated control of lights and fans.

2) Develop and implement the system in Classroom B103 of Don Honorio Ventura State University's CEA Building B.

3) Evaluate the system's effectiveness in reducing electricity consumption by comparing energy usage before and after installation.

4) Demonstrate the benefits of adopting automated systems in classrooms and public facilities to support broader energy conservation efforts.

5) Support national energy conservation goals and institutional policies.

2. Materials and Methods

2.1. Research Framework and Design

This study follows a Design and Development approach aimed at creating and implementing a Smart Motion Detection System to conserve energy by automatically switching off lights and fans when no occupants are detected. Appropriate hardware components were selected, and necessary modifications were made to the electrical infrastructure of Room B103 to ensure system compatibility.

During the development phase, a sub-meter was installed to monitor electricity consumption, which was recorded daily over two weeks before system deployment, designated as Period 1. Simultaneously, the Smart Motion Detection System and its control software were developed. Following installation, the electricity consumption of the lighting, fans, and the system itself was measured daily for two weeks, designated as Period 2. This enabled a quantitative comparison of energy usage before and after system implementation.

The collected data were analyzed to determine total energy savings, which were presented graphically. This integrated framework effectively links system development, deployment, and impact evaluation to provide a comprehensive understanding of the system's effectiveness in energy conservation within the classroom setting.

2.2. System Components and Power Supply

The system consists of a microcontroller (Arduino Mega 2560), PIR sensors (HC-SR501), relay modules, a GSM module (SIM800L), and magnetic contactors, all integrated to manage lighting and fan systems.

The Arduino Mega is powered by a 9V, 2A adapter via a newly installed 2-gang outlet. The PIR sensors and relay modules draw power from the Arduino. The SIM800L GSM module is powered separately by a 5V, 4A adapter. Relay modules included opto-isolators to protect the Arduino from the 220V AC side.

2.3. Room Isolation for Energy Monitoring

To accurately monitor Room B103's energy usage, the researchers isolated its lighting and ventilation circuits by installing a dedicated 20A breaker, a sub-meter, and a new outlet. These modifications ensured the Smart Motion Detection System operated independently from adjacent rooms.

2.4. System Wiring Diagram

The wiring diagram of the Smart Motion Detection System is shown in Figure 1. It illustrates the electrical connections among the core components, including the Arduino Mega 2560 microcontroller, PIR motion sensors, GSM module, relay modules, and contactors.

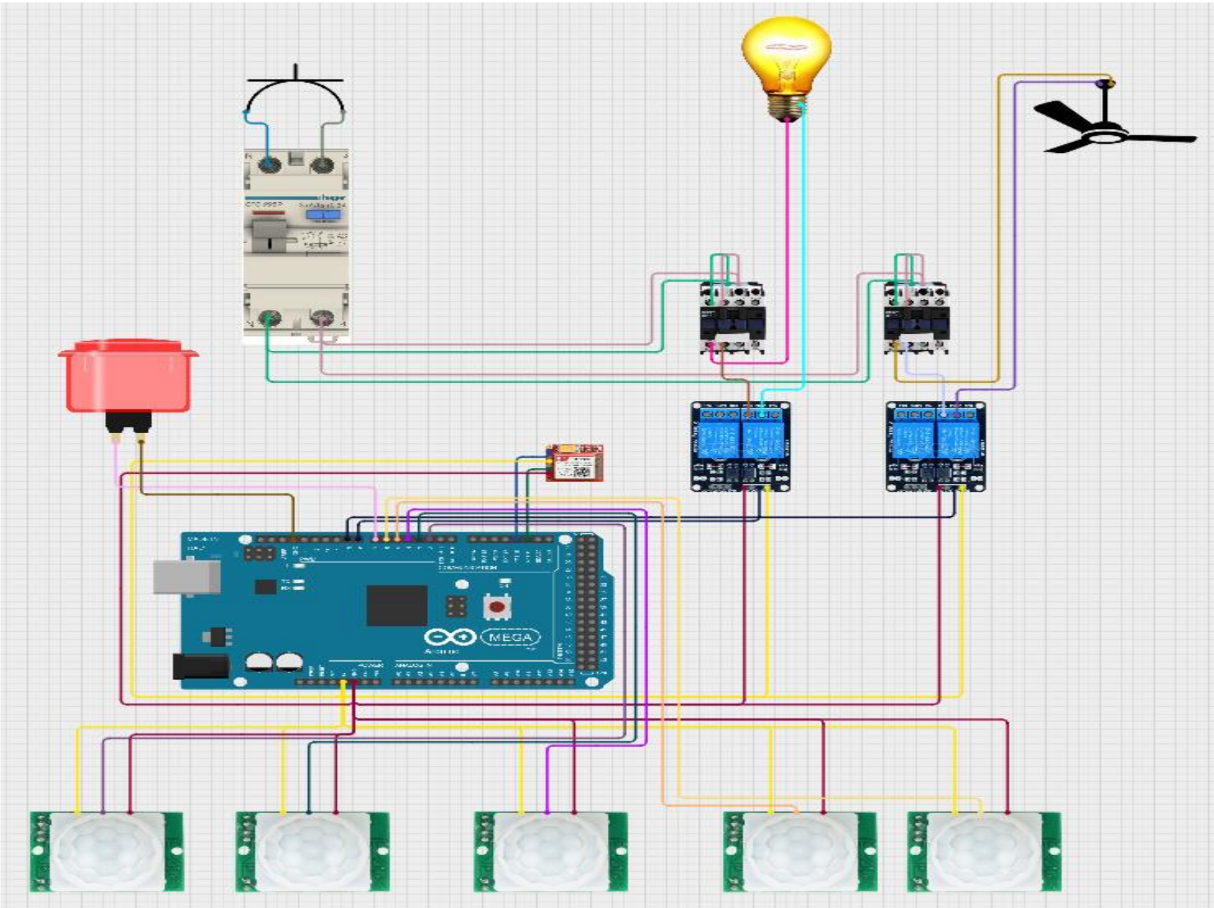

Figure 1. System Wiring Diagram

2.5. System Workflow

Figure 2 shows the workflow diagram of the Smart Motion Detection System. The PIR sensors scan for motion in 1-minute intervals. Upon motion detection, Arduino restarts the scan; if no motion is detected, Arduino commands relay modules to switch the magnetic contactors to cut power to lights and fans, conserving energy. Simultaneously, an SMS is sent via GSM to the department chairman notifying classroom vacancy. A manual override button was also added to allow users to turn on the lights and fans, restarting the motion scan.

Though previous studies suggest a 5-minute interval to avoid false vacancy detection [11],[12], this system was configured for a 1-minute interval to prioritize energy savings while still capturing valid occupancy during class.

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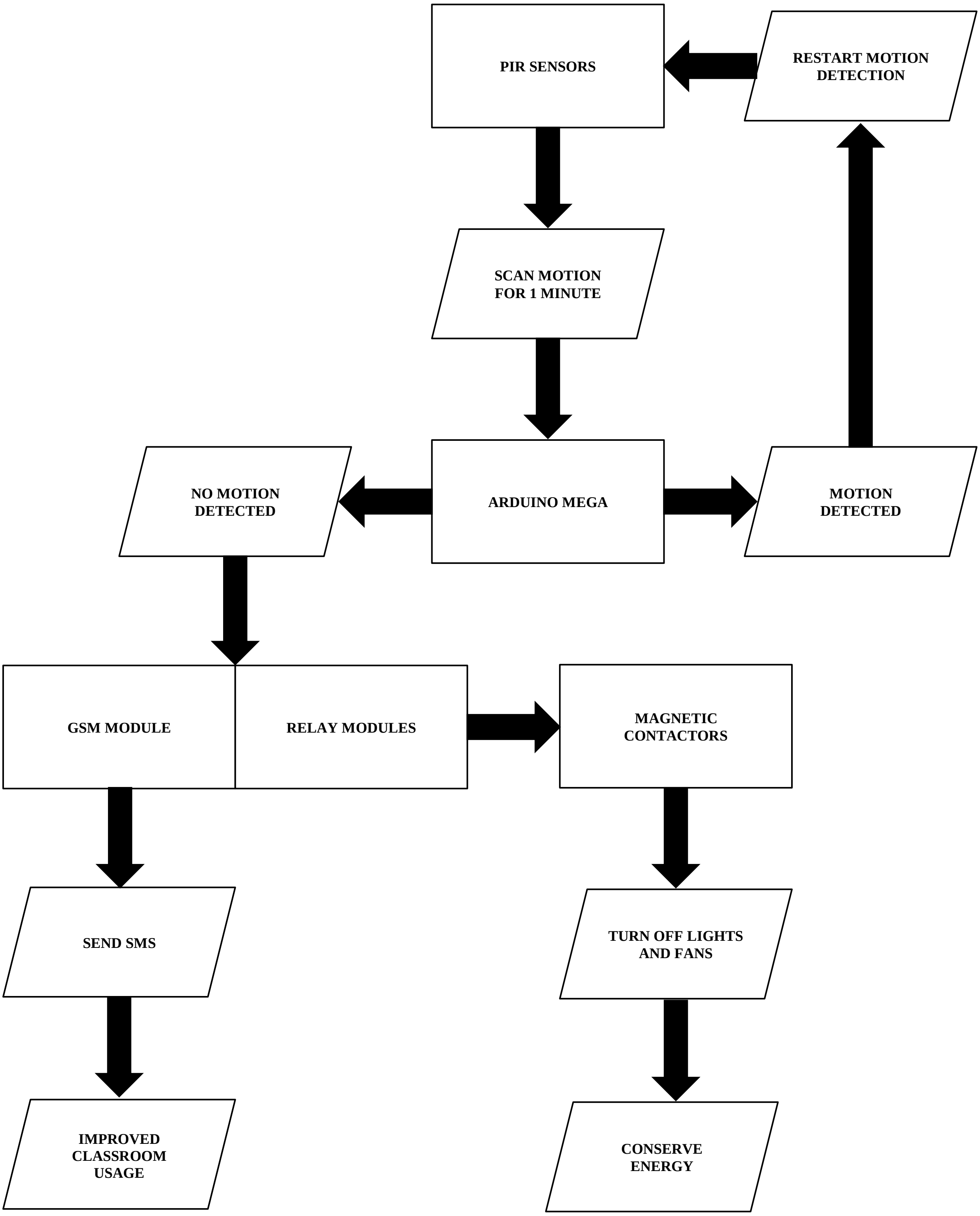

Figure 2. Workflow Diagram

2.6. Sensor Placement

Figures 3–5 show sensor layout and coverage. PIR sensors were mounted at 2.90 meters. Sensors 2 and 3 were calibrated to limit detection diameter to 6.93 meters to avoid detecting motion from outside the room. Other sensors maintained full 10.04-meter coverage. This ensured complete room coverage while preventing false triggers. Physical testing confirmed detection zones aligned with calculated projections.

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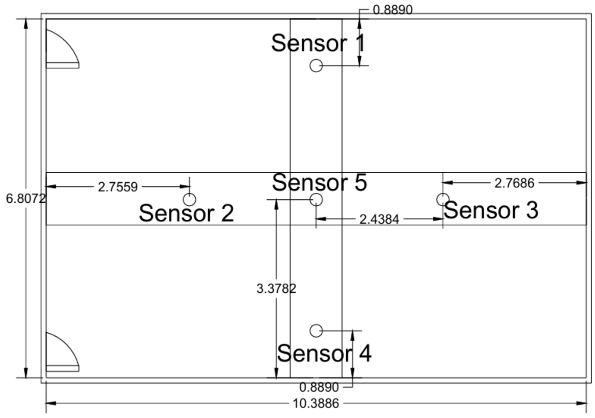

Figure 3. 2D Top View of CEA B103 with Dimensions and Sensor Placement

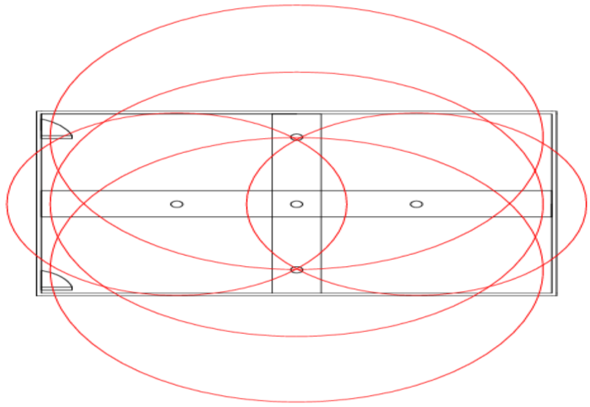

Figure 4. 2D Top View of Motion Sensor Coverage Ranges

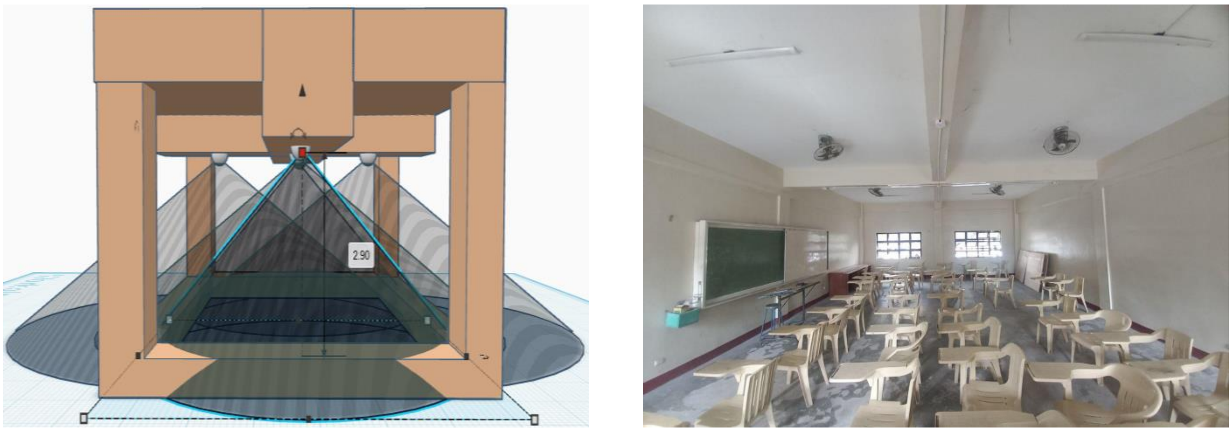

Figure 5. 3D Simulation of Motion Sensor Coverage and Actual Room Photo

The detection area radius r is computed by modeling the PIR sensor's field of view as a conical projection on the floor:

$$r = h \tan\left(\frac{\theta}{2}\right) \qquad \ldots(1)$$

Where:

r = The radius of the detection area on the ground.

h = The mounting height of the PIR sensors.

θ = The total field of view angle for the PIR sensors.

To compute the diameter D of the detection area:

$$D = 2 \times r \qquad \ldots(2)$$

For Sensors 1, 4, and 5:

$$\boldsymbol{r = 2.90 \times \tan\left(\frac{120}{2}\right) = 5.02m}$$

$$D = 2 \times 5.02 = 10.04m$$

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For Sensors 2 and 3 (effective height $h = 2.0m$):

$$r = 2 \times tan(\frac{120}{2}) = 3.46m$$

$$D = 2 \times 3.46 = 6.93m$$

2.7. Cost Analysis

The total cost of the Smart Motion Detection System is approximately ₱9,000. Key components contributing to this cost include the Arduino Mega 2560 microcontroller, SIM800L GSM module, five PIR sensors, relay modules, magnetic contactors, power adapters, and other miscellaneous electrical materials.

3. Results and Discussion

3.1. Energy Consumption Analysis

Figure 6 illustrates the daily energy consumption in CEA B103 across two 10-day periods: before and after the system's deployment. Measurements were taken from 4:00 PM to 5:00 PM on active class days. A baseline reading was established immediately following installation to ensure accurate comparison. A noticeable peak occurred on Day 8 of Period 1, where consumption reached 5.6 kWh. Considering the classroom setup, four ceiling fans (65 W each) and six light tubes (35 W each) continuous usage for 10 hours, would yield an estimated consumption of 4.7 kWh. The excess suggests possible unintentional usage beyond class hours.

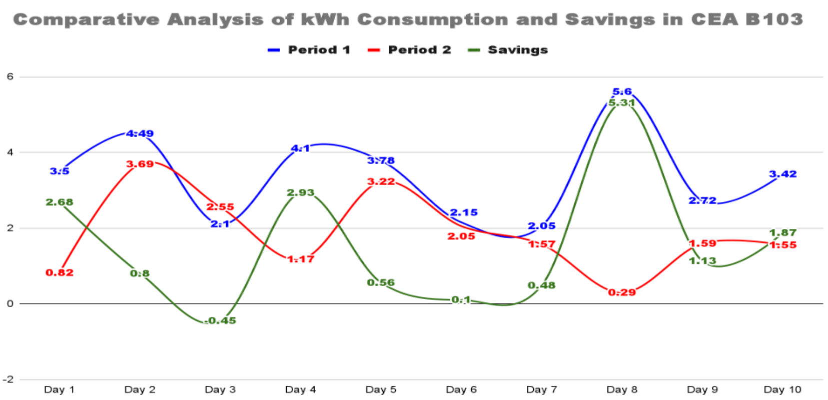

Figure 6. Comparative Analysis of kWh Consumption and Savings in CEA B103

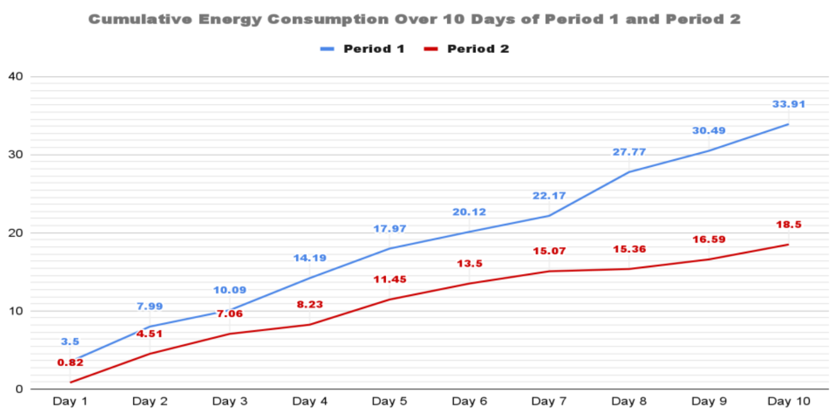

Figure 7. Cumulative Energy Consumption Over 10 Days: Period 1 and Period 2

Figure 7 illustrates the cumulative kWh consumption across the same 10-day span. Period 1 resulted in 33.91 kWh, while Period 2 totaled only 18.5 kWh, equivalent to a savings of 15.41 kWh. Using Pampanga Electric Cooperative II's rate of ₱11.2034/kWh as of April 2025 [13], this translates to a monetary saving of ₱172.64 over 10 days.

Based on this result, the average daily savings can be calculated as:

$$Average\ Daily\ Savings\ = \frac{Total\ Savings}{Number\ of\ \ days} \qquad \ldots(3)$$

$$Average\ Daily\ Savings\ = \frac{172.64}{10} = \text{₱}\mathbf{17.264}$$

From this daily average, the projected savings over longer periods are as follows:

$$Monthly\ Savings\ = \ Average\ Daily\ Savings\ \times\ 30\ days \qquad \ldots(4)$$

$$Projected\ Monthly\ Savings\ = \text{₱}17.264\ \times 30\ = \text{₱}517.93$$

$$Annual\ Savings\ = \ Average\ Daily\ Savings\ \times\ 365\ days \qquad \ldots(5)$$

$$Projected\ Annual\ Savings\ = \text{₱}17.264\ \times\ 365\ = \text{₱}6{,}301.36$$

These projections highlight the system's financial benefit when scaled over time.

3.2. SMS Activity and Room Occupancy Monitoring

During Period 2, the Smart Motion Detection System sent an average of 4.1 SMS notifications per day, primarily triggered by the detection of room vacancy. These frequent alerts indicate the system's active role in managing energy consumption by automatically deactivating lights and fans when the room is unoccupied.

After Period 2, the system was further enhanced to send SMS notifications for both occupancy and vacancy events, improving monitoring capabilities.

3.3. Operational Cost and Energy Usage of the System

Table 1 presents the estimated power consumption and daily operational cost per component based on classroom operating hours (7:00 AM – 7:00 PM). It provides a detailed breakdown of the energy usage and costs for each system element. The Arduino Mega 2560 operates continuously during classroom hours and consumes approximately 0.25 Wh per day [14].

The SIM800L GSM module alternates between idle and active modes, drawing 0.035 W in idle and up to 10 W during SMS transmission [15]. System logs from Period 2 indicate an average of 4.1 SMS messages sent daily, corresponding to roughly 8.2 activation events per day. The five PIR sensors run continuously and draw a combined power of 1.625 W [16]. Relay modules, configured as normally closed, consume 1.4 W only when the classroom is unoccupied [17].

Similarly, the magnetic contactors draw 10 W during these same periods [18]. The total operational cost was computed using the Pampanga Electric Cooperative II rate of ₱11.2034 per kilowatt-hour as of April 2025 [13]. The system's total daily operating cost results in ₱0.7318.

Table 1. System Energy Consumption

Components	Power	Daily Active Time (hrs)	Daily Energy Consumption (kWh)	Daily Operating Cost
Arduino Mega	0.25	12	0.003	₱0.0336
Sim800L (transmitting)	10	0.0228 (82secs)	0.000228	₱0.00255
Sim800L (idle)	0.035	11.9772	0.000419	₱0.0047
(2) Dual-Channel 5v Relay Module	1.4	3.7	0.00518	₱0.0580
(5) HC-SR501 PIR Sensor	1.625	12	0.0195	₱0.2184
(2) Magnetic Contactor	10	3.7	0.037	₱0.4145
			Total :	**₱0.7318**

Projected costs based on daily usage:

$$\textit{Projected Monthly Operational Cost} = ₱0.7318 \times 30 = ₱21.954$$

$$\textit{Projected Annual Operational Cost} = ₱0.7318 \times 365 = ₱267.107$$

This low operational cost highlights the practicality of the system. Even with continuous use during school hours and regular SMS notifications, the system consumes very little power.

4. Conclusion

The implementation of the Smart Motion Detection System in Classroom B103 of the CEA Building at Don Honorio Ventura State University successfully demonstrated its effectiveness in reducing electricity consumption and operational costs. By automatically controlling lights and fans based on occupancy, the system contributed to a significant reduction in energy waste and supported national energy conservation efforts in alignment with Republic Act 11285 and DHVSU's institutional policies.

The integration of motion sensors and SMS-based notifications enabled real-time classroom usage monitoring, enhancing the system's functionality. Minor adjustments to sensor calibration and notification protocols improved adaptability to varying classroom conditions. Overall, the system offers a practical and scalable solution for promoting energy efficiency in educational institutions.

5. Future Suggestions

1) Future implementations should shift to Wi-Fi-based notifications to eliminate recurring SMS costs.

2) Longer-term monitoring should be conducted across multiple academic terms to assess longer-term energy savings and system reliability.

3) Future studies should explore the effectiveness of deploying the system in more classrooms or entire school buildings to maximize campus-wide energy conservation impact.

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4) The researchers were not able to record the intervention within the set five-minute period of motion sensing by the system. If the sensor had turned off after five minutes, the researchers recommend that future tests or studies should include a record of this intervention.

5) Future studies should track how often the room is used and its activity patterns. This can help identify peak usage times and opportunities for further optimizing energy conservation strategies.

Declarations

Source of Funding

No internal or external funding was obtained for this study.

Competing Interests Statement

The authors declare that they have no competing interests related to this work.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

RSM served as the project leader and coordinated the research activities. SJAM assisted in gathering related research and was responsible, along with ANR, for recording and documenting energy consumption data. JSL and AQM contributed primarily to the installation of the Smart Motion Detection System. ATM and FRP supervised the project, providing academic guidance and critical revisions to the manuscript. All authors read and approved the final version of the paper.

Availability of data and material

Authors are willing to share data and material on request.

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